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An Automated lawncare system

Francis Wesner

Rochester Institute of Technology

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An Automated Lawncare System

by
Francis W. Wesner

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Approvals

Chief Advisor: Craig McArt

Date: 10/8/98

Associate Advisor: Doug Cleminshaw

Date: 98 OCT 8

Associate Advisor: Kim Sherman

Date: 10.8.98

Chairman: Charles Lewis

Date: 10-8-98

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Chapter 1
Introduction

This introduction serves as a guide to my thesis. In it, I identify the problem I attempted to solve, explain my motivations for wishing to solve it, and detail the methods that I used in pursuing this solution.

Problem Statement

For many years, authors, cinematographers, and futurists have shown people a vision of the future where robots help people in their everyday lives. On television, the Jetson family's home is cared for by the robot Rosie the Maid. The universe of the Star Wars movies is filled with a multitude of humanoid and non-humanoid "Droids," robots which can take many occupations including mechanic, bartender, translator, and cargo handler. The novels of Isaac Asimov ("I, Robot" and "The Robots of Dawn"), Masamune Shirow ("Ghost in the Shell" and "Appleseed"), and others, present robots which serve man as helpers, guardians, and companions.

This vision of the future has, as yet, remained unfulfilled. Robots have been limited, so far, to the areas of research and manufacturing, where they help produce cars and other goods on automated assembly lines and work in hazardous situations. There are several reasons for this. Research scientists (especially on the academic side) are generally more focused on "pushing the envelope" and developing new technologies like Artificial Intelligence, than applying the technology to practical applications. This is perfectly understandable, as this kind of work brings them recognition in their field and is important to the future development of robotics. Industry sees robots as a way to produce goods cheaply and quickly, as well as reducing workplace hazards for their workers. They need to be shown that consumer robots are both possible and practical (and that there is a market for them) before they will be able to see robots as potential consumer products.

I have chosen a robotic lawn care system as the focus of my thesis.

Motivation

I have chosen this area of research for several reasons. My first reason is that I have always had an interest in the area of robotics. My undergraduate degree is in mechanical engineering, and my original plans were to go on to graduate studies in robotics. Even though my educational goals changed, I still retain this interest. Secondly, I am familiar with the amount of time and energy that is spent on lawn care. I grew up in a rural/suburban area, and have seen and experienced the amount of effort it takes to properly maintain turfgrass. I am very aware of how much an automatic lawn care system would improve people's lives (mine included). Third, the task of lawn care is well suited to automation. It has a relatively well-defined area of operation (the lawn), it is repetitive, and it takes a great deal of human effort. Finally, I want to encourage the development of consumer robots. The robotics industry needs to be shown that consumer robots are possible and practical. I hope that the results of this thesis help to do that.

Method

The development of this thesis consists of four main areas of focus: Research, Design, the Experience, and Evaluation. Each of these steps, briefly described here, will be covered thoroughly in the following chapters.

Research

My research for this thesis focused on several main areas. These areas include:

• Robot Technology: Areas of specific research are
- sensor systems (proximity sensors, Infra-red [IR] sensors, ultrasound ranging devices, systems to determine location and heading);
- control systems and methods for path determination (how the robot determines its travel route), obstacle identification and avoidance, power management, etc.;
- battery systems, solar power, and other alternative power sources;
- communication systems including radio, IR, and ultrasound;
- and methods of determining a robot's location in its environment.

• Lawn Care Technology: Topics in this area include cutting methods (horizontal blade, helical blade, nylon wire, clippers, etc.) and their advantages and disadvantages; power sources including gasoline, batteries, and other methods (if any); and turfgrass culture and care.

• Human Factors: Research here focused on the topics of user interface (in order to design the interaction of the user - and others - with both the control system for the robot, and with the robot itself), and power equipment safety (both in developing proper warnings and in designing safety into the operation of the robot).

• Form and Aesthetics: The main focus here is the style of lawn and garden power equipment, including common forms and colors; brands and names; and the interaction of form and function (including ways that the form can aid performance, and the aspects of form that are dictated by the functions of the device). Another area of interest will be robot "style" and ways to integrate it (if at all) into lawn equipment style.

Design

The design process consisted of three phases. The first of these was determining the initial criteria for the system. Based on my research of what technologies are available and usable, I finalized a list of what features the system would have, and which technologies and devices would be used to provide these features. The second phase was to use the initial criteria as starting points to develop concepts in several different functional areas: Propulsion, Grass Cutting, Sensing, Control and Navigation, Safety, and Form. The final phase was to combine these different ideas into a final concept that incorporates all of the separate systems and features.

The Experience

The experience section focuses on describing the ways that the world interacts with, and perceives, the system. Areas focused on include the owner, neighbors, children, and domesticated and wild animals.

Evaluation/Conclusion

The evaluation phase followed my exhibition of the design. First, I examined all that I have learned over the course of my research and from the feedback I have received from my committee and others who have reviewed my work. I have used this information to come to some conclusions about the problem I have chosen to address, the solution I came up with, and the success of my solution. Secondly, I outline some possible "next steps" that could follow this thesis.

Chapter 2
Research

In this chapter, I provide an overview of the research I performed for this thesis. The chapter is divided into four main sections: Lawncare Technologies, Robot Technologies, Aesthetics, and Human Factors.

Lawncare Technologies

The first thing I researched in lawncare technologies was what power systems are used in lawnmowers. There are three basic systems used. The first is the internal combustion engine. The second is the electric motor, with power provided by a long extension cord trailing behind the mower.[1] The newest system is the electric motor, powered by one or more batteries. These batteries are typically sealed lead–acid batteries, and provide enough power to run the lawnmowers for 60 to 90 minutes on one charge.[2]

The next area I investigated was lawnmower blades and the various methods of cutting grass (Figure 1). The most popular current method is the horizontal steel blade.[3] Steel allows the blade to maintain a sharp, long–lasting edge and the weight of the metal gives the blade a large amount of inertia, which helps the blade (and motor) cut through the blades of grass without losing speed. The steel blade also has the advantage of being a single, easily manufactured part. Another popular method is the heavy nylon filament, which is used in "Weed–Whacker"® type equipment.[4] It is not as good as a steel blade, as the round filament doesn't really cut the grass but breaks off the stems through brute force. Another disadvantage is that it wears out quickly, requiring a constant feed of new filament to replace the worn parts. The advantage of the nylon filament is that it has a much lower chance of causing serious injury. A third method is the helical steel blade, as used in old–style push mowers. There have also been several other types of blades proposed in an attempt to produce a blade more effective than the nylon filament and safer than the horizontal steel blade. One is a horizontal blade made out of nylon or plastic over a core of metal.[5] Another is a horizontal blade made of

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[1] "Toro Power Lawn Mowers", [sales pamphlet] (Bloomington, Minnesota: The Toro Company, 1997) 10–11
[2] "Carefree Electrics", (Bloomington, Minnesota: The Toro Company, 1997); available from http://www.toro.com/home/lawnmower/carefree.html; Internet; accessed 15 July 1998.
[3] John Bart Sevart and R. Lewis Hull, *Power Lawn Mowers: An Unreasonably Dangerous Product,* (Durham, North Carolina: Institute for Product Safety, 1982) 11–12
[4] ibid., 165
[5] ibid., 171

loops of steel wire, which would provide a cut like the nylon wire, but have much better wear characteristics.[6] A final concept is a hinged horizontal blade, which would fold back if it struck something more substantial than grass.[7]

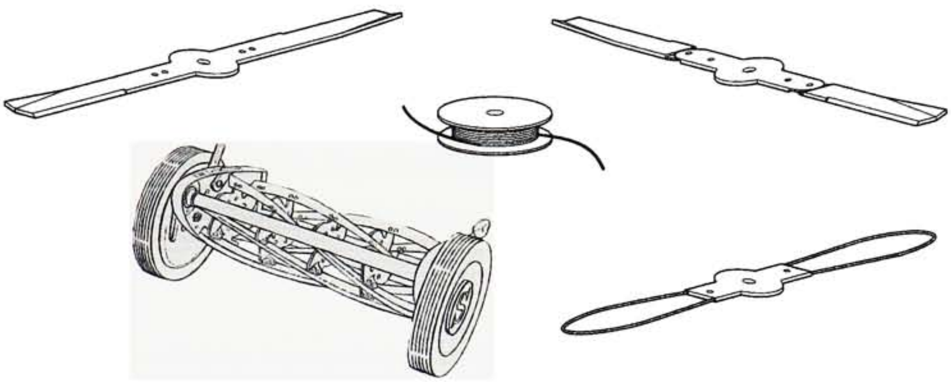

Figure 1. *Top Row, left to right:* Horizontal blade; Nylon filament; Hinged
Bottom Row, left to right: Helical blade (reprinted by permission from "Assembly Directions – Silent Scotts Mower, Models 5M2 and 10M2" (Maryville, Ohio: O M Scott & Sons, n.d.); Steel wire

The next area I researched was turfgrass culture, which is concerned with proper maintenance and care of turfgrasses (the plants that make up lawns). Among the things I learned are the ideal cutting heights for a variety of grasses and the fact that you should cut off at most 1/3 of the grass blade when you cut the lawn – any more causes damage to the plants, and leaves them unable to produce enough food for proper health.[8] I also discovered that using a mulching lawnmower – a lawnmower that finely cuts the grass clippings, and then drops the particles back into the lawn – is the preferred method of dealing with grass clippings, as the clippings rapidly decompose in the lawn and provide the plants with a good source of fertilizer.[9]

[6] ibid., 171
[7] ibid., 173
[8] "Ohio State University Extension Factsheet – Horticulture and Crop Science HYG–1190–93: Mowers and Mowing – Don't Bag It: The Lawn Maintenance Program", (Columbus, Ohio: Ohio State University, 1993); available from http://www.ag.ohio–state.edu/~ohioline/hyg–fact/1000/1190.html; Internet; accessed 15 July 1998.
[9] ibid.,

Robot Technologies

The first area I researched in robot technologies was power systems. There are several basic systems used. The majority are electric. Electricity can be provided by a cord, by on–board storage batteries, by solar panels, or by fuel–cells (a type of generator that uses a chemical reaction to produce power).[10] It can also be provided by contact with a charged surface – similarly to bumper cars getting their power by running a wire up to touch a power grid on the roof of their enclosure. Another method is to use an internal combustion engine to both provide direct motive power, and to drive a generator to make electricity for the robot's computer systems.[11]

The next area of robot research was methods used to communicate between robots and external control systems. The first method is by direct connection – a wire run between the robot and its controller.[12] There are also several wireless methods. The most standard is by either radio signals or by coded infra–red transmissions. Another method is to use patterns of LEDs and a video system to provide the control system with the robot's system status.[13]

The third area I investigated was sensing methods. Sensors allow the robot to interact with the world – they provide information about the robot's environment, including landmarks, obstacles, and other hazards. The sensors used in robots are divided into two main categories: contact (sensors that require physical contact with what they are sensing) and non–contact. Contact sensors include strain gauges (circuits inlaid on surfaces that sense when the object they are attached to is having force applied to it),[14] pressure pads, and antennae or whiskers (wires that stick out from the robot, and close a switch when they are bent by contact with an object).[15]

There are many kinds of non–contact sensors, most of which operate by emitting some form of energy, and then picking up the returning waves of energy that have reflected off

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[10] "What is a Fuel Cell", (Washington, DC: The Fuel Cell Commercialization Group, 1997); available from http://www.ttcorp.com/fccs/fc_what1.html thru /fc_what4.html; Internet; accessed 15 July 1998.
[11] Hans Moravec, "Machines with Mobility" in *Robots*, ed. Peter Marsh, (New York: Crescent Books, 1985) 73
[12] Gordon McComb, *The Robot Builder's Bonanza*, (New York: TAB Books, 1987), 5–6
[13] Douglas W. Gage et al., "Other Communications Channels" in *Many Robot Systems*, (NRaD Robotics: 1997); available at http://www.spawar.navy.mil/robots/research/manyrobo/otherchans.html; Internet; accessed 15 July 1998.
[14] John J. Craig, *Introduction to Robotics Mechanics and Control*, (Reading, Massachusetts: Addison–Wesley, 1986) 287
[15] McComb, *Robot Builder's Bonanza*, 224–26

objects in their path.[16] These sensors can use infra–red light, laser light, ultrasonic and sonar waves, and radar waves, among others. Another method of non–contact sensing is to use video cameras.[17] The images that are picked up by the cameras can be compared to a standard image of an area in an attempt to sense changes in the environment, or they can be fed through pattern–recognition routines, which try to identify objects by their shapes.

Another use of non–contact sensors is to determine the location of the robot. One method is with directional sensors that read the angle between their position and a beacon located on the robot.[18] Several of these sensors placed around an area can be used to triangulate the location of the beacon. Another method is to use a Global Positioning System (GPS),[19] which is basically the same idea as the directional sensors (triangulating the position), but on a much larger scale – with the sensors located on satellites in orbit.

The fourth area of research was in methods of locomotion. The most common system is wheels – three or more – with the steering being provided either by wheels that pivot or by opposed, separately driven wheels. Other common methods are tracks and legs (four or more). Less common locomotion systems include hovering (on an air cushion) and a variety of systems involving one, two, or three legs (none of which are very practical at this point).[20]

The final area of robot research was in control systems. The control system is the "brain" of the robot. There are a variety of characteristics that the control system can have. It can be either an external system that must have some method of communicating with the robot, or it can be a built–in (or "onboard") system, in which case the robot is on its own while it is out operating. The system can be an artificial intelligence, which can learn and develop new behaviors for interacting with its environment, or it can consist of a set of routines and behaviors that it applies to its situation based on a set of programmed rules. The control system can be "taught" to do its job in several ways: it can be programmed on a computer, it can be run through its task on remote–control, or it can be directly taken through its task by a human operator. All of these various systems use sensors to receive information about the

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[16] John Iovine, *Robots, Androids, and Animatrons*, (New York: McGraw–Hill, 1998) 57, 65, 83–5
[17] ibid., 78–9
[18] "Radio Direction Finding", (BMG Engineering Inc, 1998); available at http://members.aol.com/BmgEngInc; Internet; accessed 15 July 1998.
[19] Iovine, *Robots, Androids, and Animatrons*, 83
[20] McComb, *Robot Builder's Bonanza*, 10–11

robot's environment and state, and use actuators (arms, motors, signaling devices, and others) to interact with and change that environment and state.[21]

Aesthetics

The first area of research in aesthetics was the style of consumer lawn equipment. In form, most lawn equipment is functional. The messages given by its appearance suggest ruggedness, safety, and method of use. The materials are mainly molded plastic for the housings, and metal for the moving parts. Color schemes are bold and contrasting, and either suggest "plant" themes – like John Deere's green and yellow, and Black and Decker's green and black – or use colors that contrast with the lawn, like Toro's red and black scheme. Many other companies' color schemes are chosen to suggest the colors of major competitors – for example, there are several manufacturers that use green–and–yellow patterns similar to John Deere's.

Robot style, my next area of aesthetics research, is divided into three directions. One, the research and industrial form, is typified by function. Since most of these robots are used in laboratories or factories, little thought is given to appearance. Mechanisms are exposed, wiring is visible, and housings are simple, straight–forward, and low in cost. Most research robots – like the Mars surveyor robot, Sojourner – are unpainted and have lots of exposed metal. Consumer robots, on the other hand, are very concealed and playful – this is due to the fact that many of them are used either as toys or promotional devices. They are anthropomorphised; many have faces and other human features. Many have colorful plastic housings. The two main trends in consumer robots are "cute" and "high–tech". The final source of robot style is science fiction movies and television shows. These robots are either very human–looking – Data from *Star Trek: The Next Generation*, and C3P0 from *Star Wars*, for example – or they are highly stylized visions of the functional research robots – R2D2 and many of the other Droids from *Star Wars* are good examples of this.

Trends in product naming is another area I researched. In the area of lawncare, there were several trends I discovered. One was to name lawnmowers aggressively – like the *TurfTiger* or the *Magnum III* from Scag.[22] Another, more important trend was to imply the advantages of the mower in its name. For example, the Toro *Recycler*™ lawnmowers are all

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[21] Geoff Simons, *Robots – The Quest for Living Machines*, (London: Cassell, 1992) 95–104
[22] "Scag – The New Breed of Cost Cutters 1998", [sales pamphlet] (Mayville, Wisconsin: Scag Power Equipment, 1998) 4, 10

mulching mowers that recycle the grass clippings back into your lawn.[23] The *Turf Tiger* and the *Magnum III* are large and powerful mowers. The *Turf Tracer* has a floating cutting deck that allows it to "trace" the contours of the ground as it cuts.[24] The *LawnPup* is a small, compact mower.

Names for robots come from two main sources: research laboratories and toy companies. Research robots are named by professors and graduate students, and tend to either be names that reflect the purpose of the robot, or be "cute" names. Examples include the *Terragator* (designed to travel over rough terrain), the *Hexapod* (it had six legs), *Robart*, *Koala*, and *Pluto*. Consumer robots (toys, for the most part) follow similar naming conventions, although more polished and "cute" for the consumption of children. Some of these include *Topo*, *Omnibot* (it has several functions), *Verbot* (it works by simple voice command), and *Dingbot*, which reacts to things it bumps into.[25]

Human Factors

The first area I studied in human factors was power tool safety. There are several techniques used to increase safety in power tools.[26] The first is the application of warning and instruction labels.[27] Highly visible and easily understood (by those who read the language or accurately interperet the pictograms), these labels can make the user aware of any dangers they face in the operation of a tool. Another is the use of "dead–man" switches.[28] These are power switches that must be held down to stay on – if the user takes his hand off of the handle that the switch is on, the power tool automatically turns off. Other safety methods are to locate handles and other controls where they will keep the user's limbs away from moving parts, to provide two handles so that the user has to have both hands in known places at all times, and to design the tool so that there aren't any other parts that the user can use as handles.[29] Yet another method is to protect the moving parts with guard devices that make it very difficult for the user

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[23] "Toro Power Lawn Mowers", 10–11
[24] "Exmark – Professional Turf Care Equipment", [sales pamphlet] (Beatrice, Nebraska: Exmark, 1997) 14–15
[25] Peter Matthews, "The Rise of the Micro" in *Robots*, ed. Peter Marsh (New York: Crescent Books, 1985) 105
[26] William H. Cushman and Daniel J. Rosenberg, *Human Factors in Product Design*, Advances in Human Factors/Ergonomincs, vol. 14, (New York: Elsevier Science Publishing Company, Inc., 1991) 315–31
[27] ibid., 327–30
[28] "Defining Terms", (Stillwater, Oklahoma: Oklahoma State University, 1997); available at http://www.pp.okstate.edu/ehs/module3/mower/unit1.html; Internet; accessed 15 July 1998.
[29] Cushman and Rosenberg, *Human Factors*, 284–92

to contact them.[30] The difficulty is doing this while still allowing the moving parts to function correctly, particularly the blades.

I researched three main things in the area of user interface. The first was the physical interface between man and tools. Topics included size and placement of buttons and handles, and appropriate weights and carrying positions for tools .[31] The second area was warning systems,[32] including types of warnings (auditory, visual, tactile)[33] and appropriate colors, patterns, and intensities.[34,35] The third area I researched was computer interfaces. Topics of study included screen layout, interface design, input methods,[36] and web page design guidelines.[37]

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[30] Wesley E. Woodson, Barry Tillman, and Peggy Tillman, *Human Factors Design Handbook*, 2nd ed., (New York: McGraw–Hill, 1992) 517–19, 789
[31] ibid., 424, 507–513
[32] Mark S. Sanders and Ernest J. McCormick, *Human Factors in Engineering and Design*, (New York: McGraw–Hill, 1987) 547–52
[33] Woodson, Tillman, and Tillman, *Human Factors Design Handbook*, 383–5, 417
[34] ibid., 386–8
[35] Sanders and McCormick, *Human Factors in Engineering and Design*, 130–33
[36] Susan Weinshenck, Pamela Jamar, and Sarah C. Yeo, *GUI Design Essentials*, (New York: John Wiley & Sons, Inc., 1997)
[37] Elizabeth Castro, *HTML for the World Wide Web*, 2nd ed., (Berkeley, California: Peachpit Press, 1997)

Chapter 3
Design

This chapter describes the design development of the Automated Lawncare System. The first section lists the initial design criteria I determined from my research. The following sections describe the initial concepts and designs in the areas of Propulsion, Grass Cutting, Sensing, Control and Navigation, Safety, and Form. The final section details the final concept that I developed from these separate ideas.

Initial Criteria

The first step after completing my research was to decide on a list of technologies, features, and capabilities I wanted the ALS to include. At the most basic level, the system had to mow the lawn. To do this, I decided it should use a horizontal, steel, mulching blade, driven on a four wheeled, battery powered chassis. At a higher level, the robot would have to react to, and interact with, its environment. This required a control system, which I decided should be external, so that the owner would always have access to it. To go along with the control system would be a system of directional sensors to locate the robot's position, and an array of both contact and non–contact sensors on the robot to allow it to detect obstacles and other hazards. The non–contact sensors would be ultrasonic, since light–based sensors could have trouble during daylight, and video–based systems are very complex and require very powerful control systems to make them effective. Finally, I decided that the system should be safe enough to deal with children, animals, and visitors unfamiliar with it; require minimal maintenance on the part of the owner; and be non–threatening in attitude.

Concepts – Propulsion

Even after deciding on a four–wheel propulsion method, there were still a variety of possible designs. Most of my concepts were the standard rear–wheel drive, front–wheel steering. I did try some that reversed this, as well as a "diamond–patterned" concept that had single front and rear casters, and two, opposed–drive wheels in the middle. This didn't turn out to be very practical. Eventually, several people pointed out that the standard four–wheel design was leading me in circles – all of my design concepts for the robot were looking either like cars or normal lawnmowers with the handle removed (Figure 2). In response, I switched my focus and tried a variety of concepts with three wheels. Having the single wheel in the

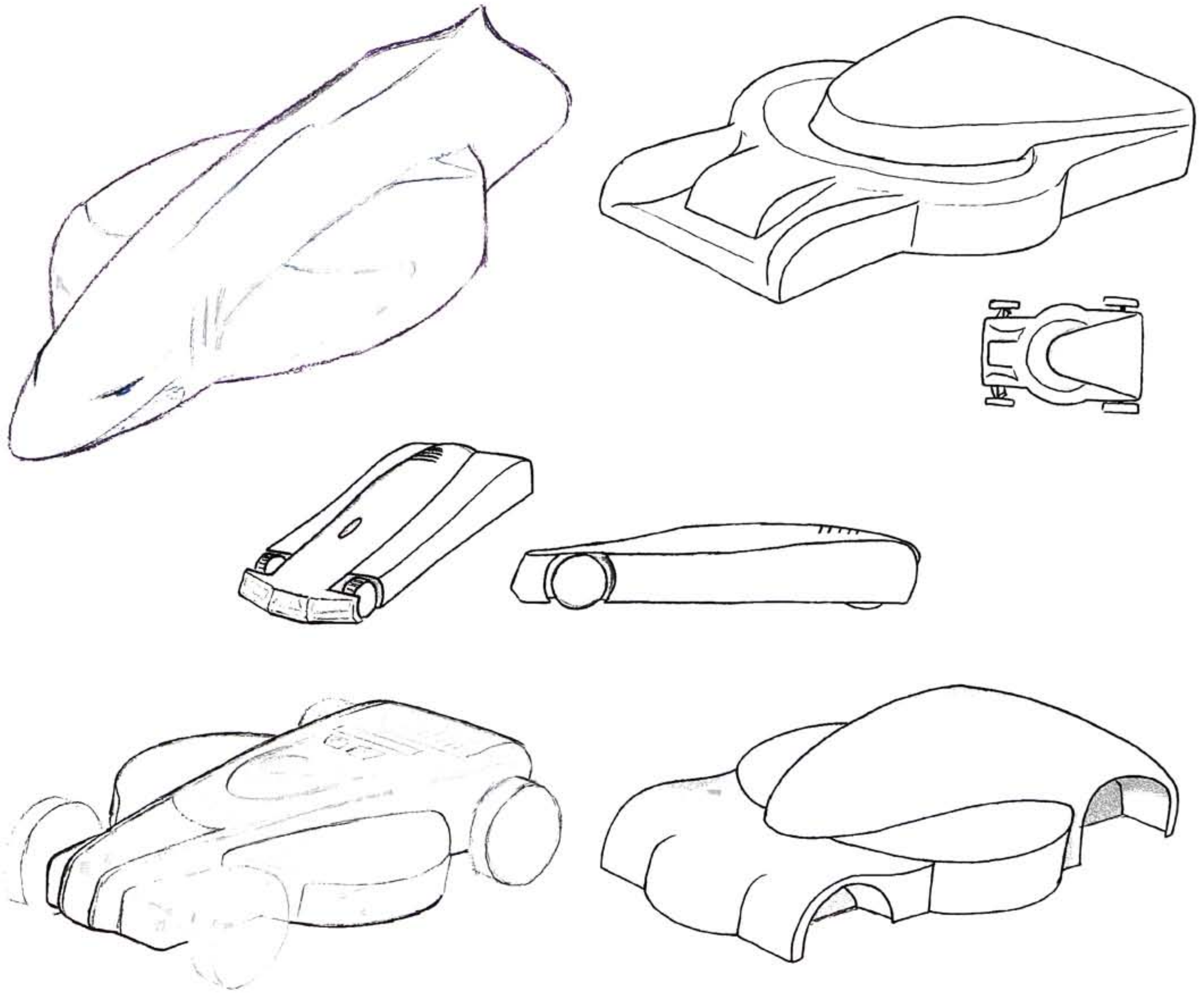

Figure 2. Four-wheel Form Concepts

front didn't work very well, as it didn't combine well with other design features – especially the sensor systems. The final configuration I settled with was two drive wheels in the front and one steering wheel in the back (Figure 3).

Concepts – Grass Cutting

All of my initial designs were based around a standard 18 to 21 inch steel lawnmower blade. I eventually realized, however, that with the addition of the robot's control and drive components, the system was getting too large – 34 to 40 inches long, and 20 to 23 inches wide. Taking a cue from the larger mowers on the market, I then attempted to design a system of several smaller blades that would still produce a wide cutting path (Figure 4). Finally, I realized that since the system is robotic, it didn't need the wide cutting path, the main purpose of which is to reduce the amount of time the operator spends mowing. Since the system is patient and could take all the time it needed, a smaller blade would be fine. I finally settled on a single 12 inch steel mulching blade set in a standard cylindrical blade enclosure.

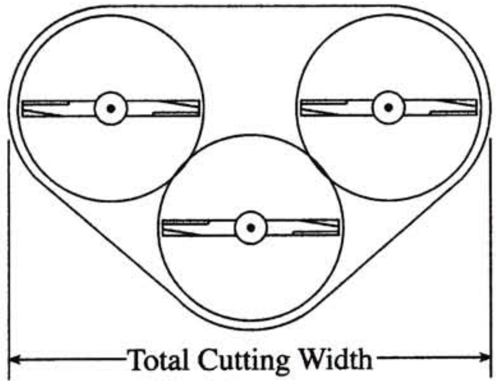

Figure 4. Multiple–blade Cutting System.

Concepts – Sensing

The sensor design was divided into two subsystems – the contact sensors and the non–contact sensors. For the contact sensors, there were two main concepts. One was to put sensors on the points of attachment between the outer body and the chassis. This would allow the robot to sense when force was applied to its hull and probably which direction the force was applied from. The other option was to put strain gauges on the axles of the robot. This

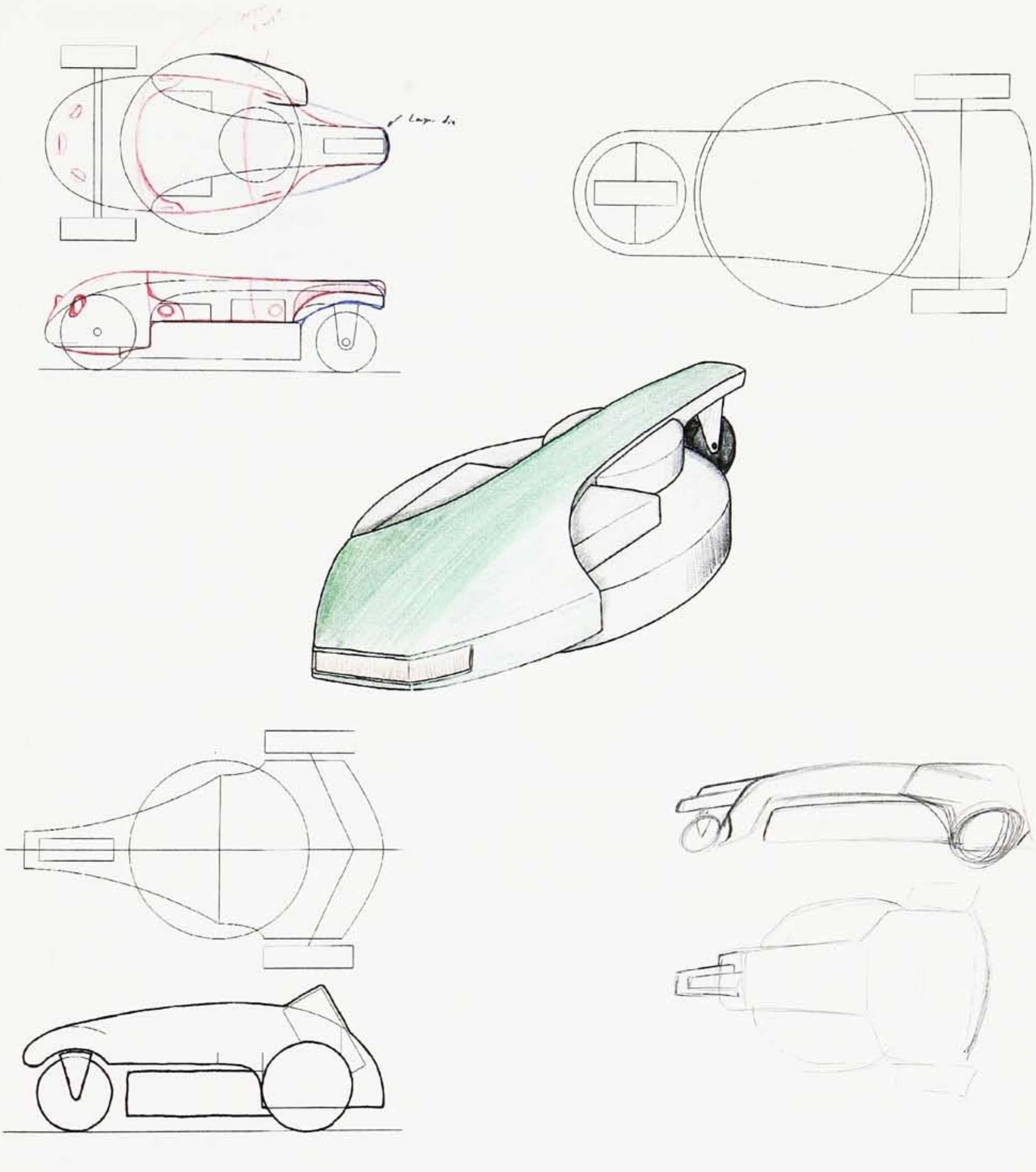

Figure 3. Three-wheel Form Concepts

would give the same functionality as the first concept, and would also be able to sense if one or more of the wheels had left the ground. This is the system I decided on.

The non–contact sensors had to have as close to a 360 degree view as possible for several reasons. First, they need to see front and rear so that the robot can guide its steering when traveling forward or backward. Second, they need to see all around in order to detect moving hazards approaching from any angle. They don't really need to see up, as any flying objects approaching the robot would most likely be moving too fast for the system to react to. Based on these requirements, and taking into account the form of the robot, I came up with several concepts. One concept was to place a ring of sensors on a tower atop the robot. Others included continuous bands of sensors running in strips along the robot's sides, and groups of "eyes" in various places. The final concept was heavily influenced by the form of the outer body and was an outgrowth of the "eyes" concept (Figure 5).

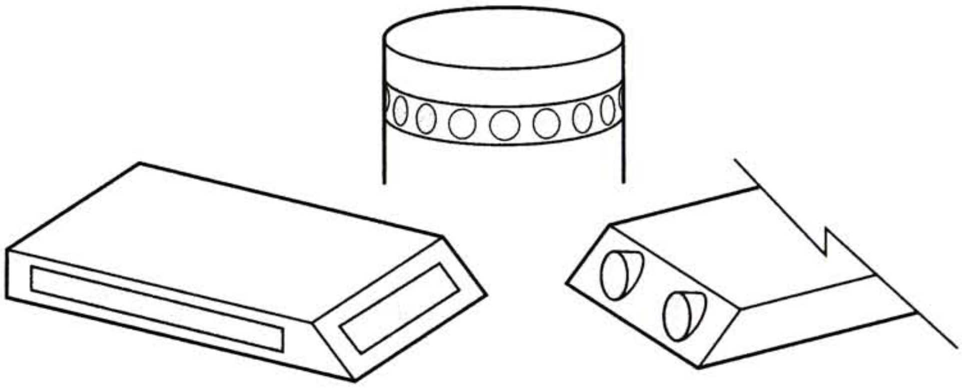

Figure 5. Sensor Concepts
Left to right: Sensor bands, Tower, "Eyes."

Concepts – Control and Navigation

There were two focuses in developing concepts for the control systems – the physical components of the system and the behavior of the system. The physical parts of the system included the direction sensors, the system controls, and the "home base" of the robot. The original idea I had for the directional sensors was to place a pair of them at opposite corners of the yard (so that the robot's operational area was completely between them), but I soon realized that it made more sense to place the sensors at either end of the owner's house. This would allow them to be more easily wired into the system – no wires would have to leave the confines of the building – and would also reduce the number of times that the robot would be directly between the sensors (which would make it impossible for them to accurately triangulate its location). My concept for the system controls included two possible forms. One would be a touch–screen console which would be attached to a convenient spot on the wall of the house, by a window looking out on the main yard, in the garage, etc. – whatever was best for the owner. The other form would be a link to the owner's personal computer, which would have the control software installed on it – basically, another step towards the "smart home." The robot's "home base" would house the recharging jack that would provide it with power as well as one of the radio antennae that would be used for communications between the system and the robot. Testing would have to be done to determine if the one antenna would be enough. If more were required to ensure good contact, they would be installed with the directional sensors. My original concept for the home base was a small doghouse style structure that would completely enclose the robot. I realized, however, that this would make an attractive shelter for a variety of animals, as well as being quite large. The final design I settled on was a small "dock" that the robot would back into – basically just the power jack and enough structure to support it and provide the robot with some alignment assistance when it backed in.

The behavior of the system didn't really go through a variety of concepts; for it evolved as my discussions with my committee and other people revealed further concerns and situations that had to be dealt with. The different situations that the behavior had to deal with include the basic mowing routines, ways to deal with both stationary (fallen branches, toys, etc.) and mobile (children, pets) hazards, and safety and security concerns. The final set of behaviors will be discussed in the Final Concept section below, and further elaborated in Chapter 4.

Concepts – Safety

There were two main safety concerns to be addressed – the robot running into or over something, and someone reaching into the blade enclosure. The concepts I generated were heavily influenced by the sensor concepts that I was working on at the same time. My initial safety systems were based on contact sensors. They would detect something coming in contact with the robot, to which the robot could then react. For the blade, I imagined some kind of "skirt" between the bottom edge of the enclosure and the ground, that would detect anything inserted below the robot. As the non–contact sensor concepts became more concrete, my safety concepts became more active. With the use of the ranged sensors, the robot would be able to see hazards before it got to them, and react before it came in direct contact by either avoiding the hazard or by stopping and turning off the blade if the hazard approached on its own. Other safety concepts included the use of some kind of "in operation" indicator, such as an operation light or a "spinner" attached to the blade shaft that could be seen through a ring of windows in the hull, and would indicate to an observer if the blade was spinning. A final safety concept I had was to put some sort of "blade guard" on the robot, similar in concept to the screens on electric razors – a physical barrier that would allow grass to come in contact with the blade, but would prevent larger objects (like fingers) from doing so (Figure 6).

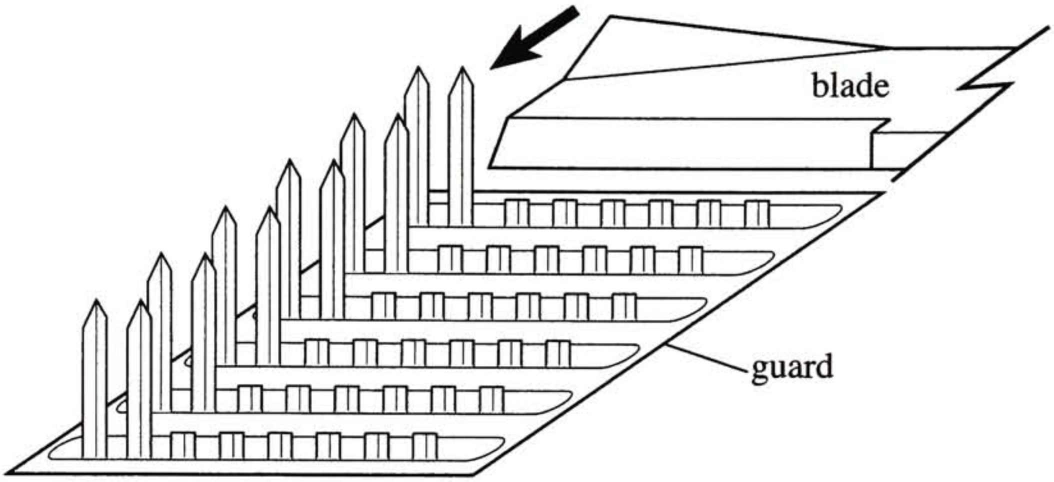

Figure 6. Blade Guard Concept

Concepts – Form

Over the course of this project, I developed many form concepts for the robot. These concepts were strongly influenced by whatever the current state was of the concepts in the previously mentioned areas, as well as my goals for the system. I wanted the form say several things: that the ALS was a robot, that it was a professional piece of equipment (not a toy), and that it was durable and functional. I also wanted it to give a suggestion of its operation. Not all of the concepts were successful in these goals.

My first concepts were based around the four–wheeled chassis as well as an 18–20 inch blade system. Many of these only included hints of where sensors would be, as I was still developing the sensor concepts. Among the ideas I experimented with were the decision between exposed and covered wheels, using forms from lawnmowers to show function, and ways to place contact sensors. I even took some side–trips into the idea of using animal forms (Figure 2). As was stated earlier, in the Propulsion section, most of these concepts resembled either small cars or lawnmowers without handles, so I decided to see what I could do with three wheeled concepts.

By the time I started on the three–wheel concepts, the other aspects of the design were becoming more concrete, and I was able to give more attention to making space allowances for interior components, as well as having a better idea about external features. It was also at this stage that I added the idea of having the form be non–threatening. I realized that a *really* high–tech, "professional" robot moving towards someone through the grass could be considered threatening by some. My first concepts had the single wheel in front, but I soon realized that it was difficult to fit the sensors and other components in the front when there was a wheel in the center of it, so I started doing designs with the single wheel in the rear. Another idea I worked with was the concept of a modular system. The hull, with the sensors, motor, etc. would be one part, and the blade system would be another. The blade system could be replaced with other systems (such as a fertilizer spreading system) as they were developed. This led me to a concept, which I explored in several other designs, of contrast between the body and the mechanics of the robot (Figure 3).

Final Concept

The final combination of all of these separate subsystems is the Automated Lawncare System (Figures 7, 8, 9, and 10). It uses a three wheeled propulsion system, with two drive wheels in the front and a single steering wheel in the rear. The blade is a 12" horizontal, steel mulching blade. A system of ultrasonic sensors – 3 each to the front, left, and right, and 1 to the rear – allows the mower to detect hazards before it reaches them. It also uses a set of strain gauges to detect external forces applied to the body and axles. The safety features include the use of the ranged sensors to detect and react to hazards before they can become a danger. Since it's wise to have multiple safety systems in case something goes wrong with one, the system also include an "operation" light, which is also an emergency stop button (similar to the ones in machine shops). A final safety feature is the use of a blade guard. The form of the ALS comes from several thoughts. The color is a combination of those in lawncare products and robotics – grass green for the "main" body and machine gray for the more mechanical parts. This coloration also points out a message of contrast – contrast between the green, shiny, smooth body and the gray, matte, blocky, and functional section. The front of the robot, with its "bug–eyed" sensors and rounded "head" gives a suggestion of some sort of friendly creature – the robot as harmless companion and helper. Finally, the form of the green section of the body – wide at the front, trailing off towards the rear – along with the form of the sensors, gives a

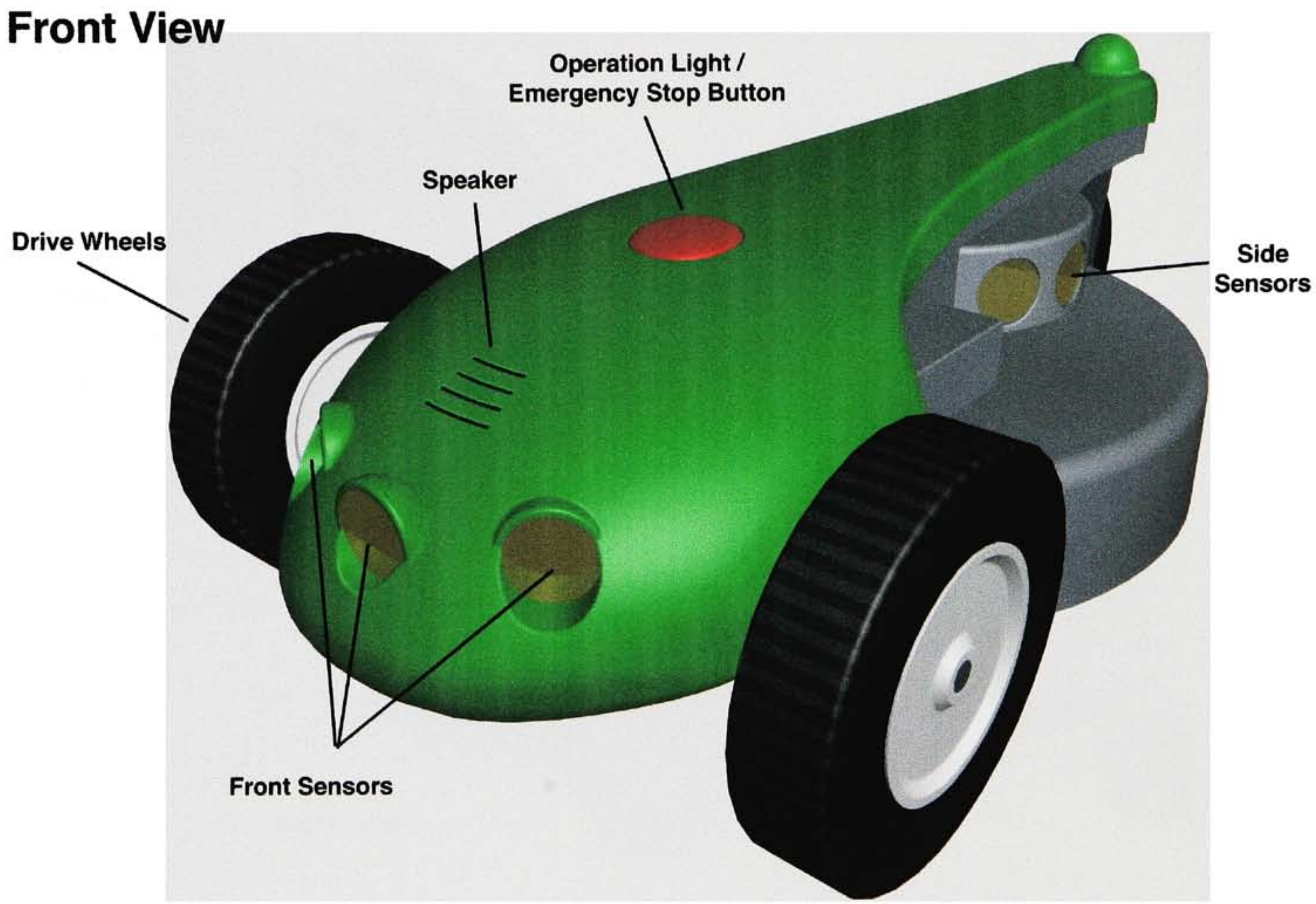

Figure 7. Final Concept - Front View

Rear View

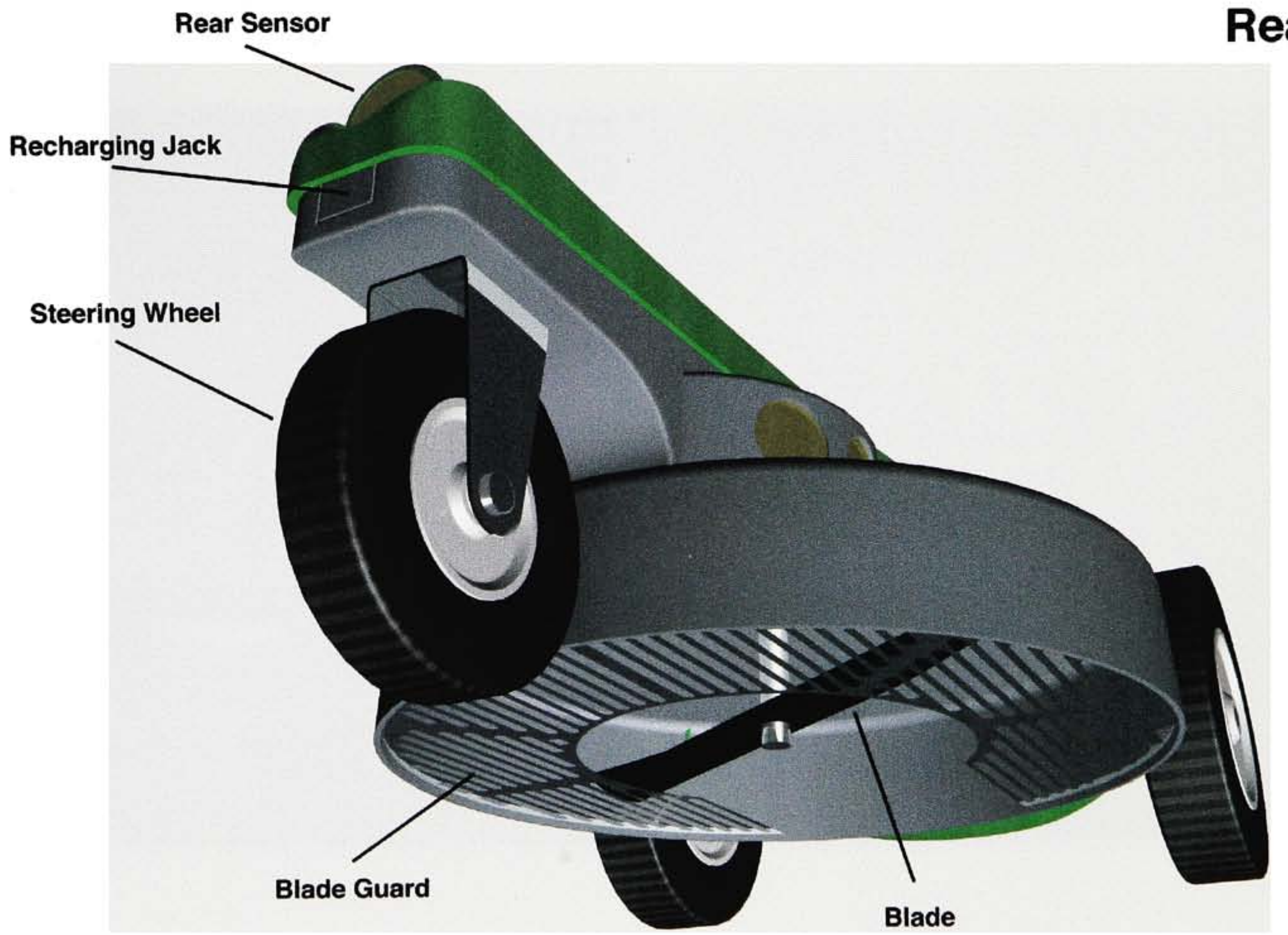

Figure 8. Final Concept - Rear View

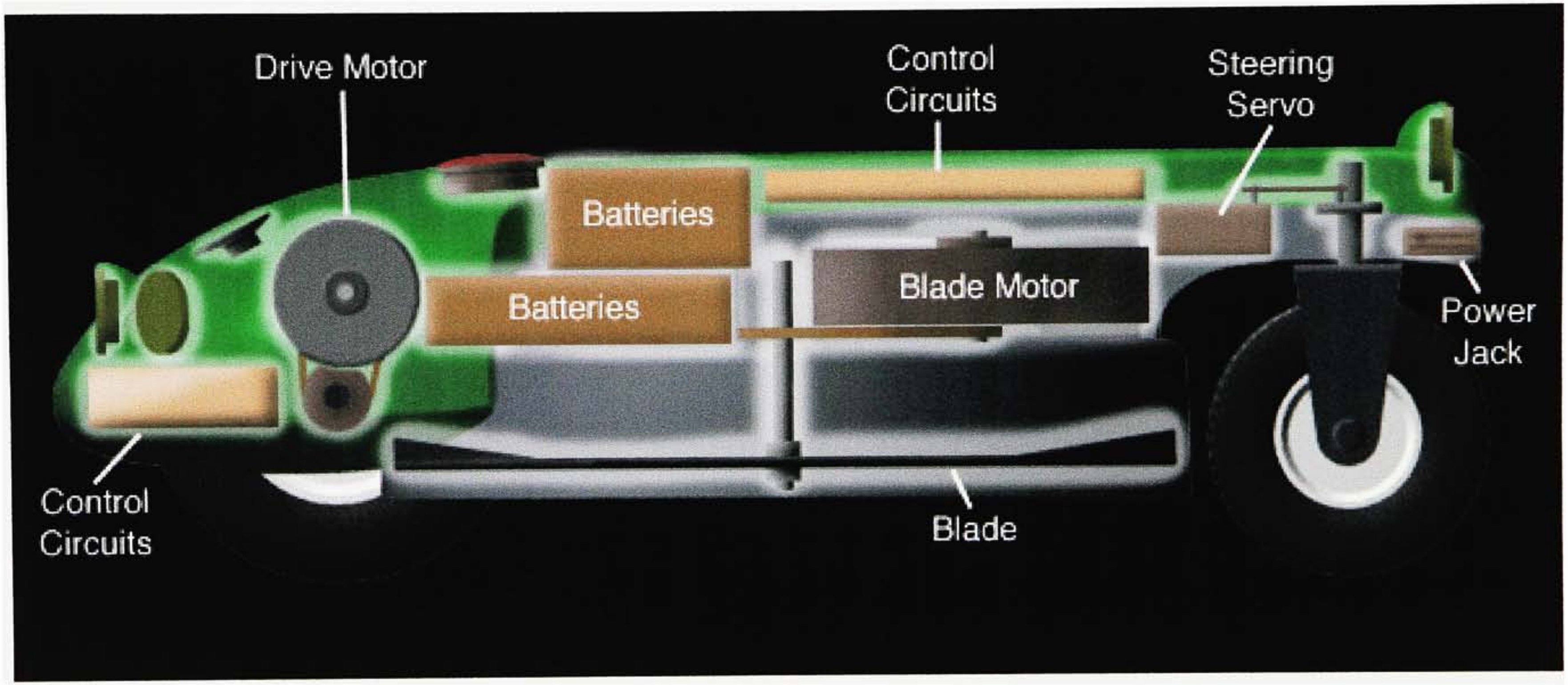

Figure 9. Final Concept - Interior Component Layout

Figure 10. Final Concept - Model Photos

strong directional message, identifying the front of the robot and its normal direction of movement.

The control system consists of a small touch–screen terminal (or link to a home computer), the recharger base for the robot, and two directional sensors. There are three basic behavior patterns for the system: normal operation, responses to static hazards, and responses to mobile hazards. In normal operation, the robot starts out at its base and then travels the lawn in the pattern the owner has chosen on the control system. If it runs low on power before completing the lawn, it returns to its base to recharge and then goes back and finishes its task. If the ALS encounters a static hazard – a branch or bicycle lying in the lawn, for example – the control system steers the robot around the object and then continues with its normal pattern. It marks the location of the object on an on–screen map, and alerts the owner. Later, the owner can go out to the lawn, remove the hazard(s) the system had to avoid, and then tell the system that the objects are gone. The robot will then go back out onto the lawn and mow the areas it had to skip. If the system detects a mobile hazard – a child playing, an animal, etc. – it would react several ways depending on what happens. If the moving object stays at a distance, the robot would keep an "eye" on it and continue with its job. If the hazard approaches the robot, the robot will immediately stop moving, stop the blade from rotating, and project an audio warning – either a spoken message or some form of alarm, at the owner's choice. If the hazard remained nearby, the robot would repeat its warning at intervals and would continue to wait. After some period of time, it would send a message back to the control system to alert the owner of the problem. If the hazard stopped moving and stayed immobile, the system would eventually declare it to be an immobile hazard, and would drive around it – giving the hazard, however, a wider berth than it would normally.

Chapter 4
The Experience

In this chapter, I detail how the world perceives and interacts with the system. The purpose of these "experiences" is to help us get a clearer image in our minds of how it would actually be to own, operate, or interact with the Automated Lawncare System (ALS) in real life. The points–of–view that I will attempt to describe are from the owner, the visitor, the neighbor, the child, the animal, and the criminal. All of these different people would have their own expectations, perceptions, concerns, and reactions to the system.

Owner

The first interaction between the owner and the ALS is the decision to purchase the system. The are several possible reasons for this purchase. Some buyers may be long–time home owners who are tired of 'wasting' the time it takes to care for the lawn. Others may be new home owners who, having realized the 'American Dream' of a suburban home, are now faced with the fact that that home will take up a lot of maintenance time, and that they don't want to give up their free time or hire a mowing service. Other buyers may be technophiles who like to always have the latest 'cool toys,' or people who wants to impress the neighbors. They may have been considering a new lawnmower purchase, and been convinced by advertisements, reviews, and salesmen that the ALS is the best current solution for his needs. All of these reasons could lead the owner to purchase the system.

Once the purchase has been made, the next step will be to have the system installed. The installation needs to be performed by a technician from the store where the owner purchased the ALS. First, the locator beacons are installed at appropriate locations on either end of the property, most likely on two sides of the owner's house. Wires are run to where the owner would like the control system installed. This control system can be either a stand–alone unit that can be mounted on a wall or table, or a link to the owner's personal computer. Next, the technician, following the owner's guidelines, feeds a map of the owner's lawn into the control system, using the locator beacons and a tracing wand – a device whose location can be read by the beacons just like the system's robot. The owner decides which areas of his lawn he wants the ALS to mow, and which not to. Then, with advice from both the system (based on its analysis of the map) and the technician, the owner decides where he wants the robot's base to be. It is then installed and hooked up to the house's power grid. Finally the robot is placed in the base, and the technician leads the owner through the basics of using the system (programming the control system, routine maintenance of the robot, and so forth).

When the time comes to operate the system, there are two basic options. First, the system can be set up to follow a regular schedule: every Tuesday at 12PM, for example. The second option is for it to run when the owner tells it to (i.e., the owner would go to the control system, and order the system to start immediately). Further sub–options that the owner could choose include picking other mowing patterns (mowing east/west one day, then north/south the next, for example), and what kind of warnings to use for the safety routines (voice, alarms, low or high volume, etc.). In a normal operation cycle, the robot would follow the chosen mowing pattern until the whole lawn was mowed, and then return to its base. If it ran low on power, the robot would return to the base to recharge, then continue the pattern where it left off. In the event the system found debris or obstacles in the lawn, it would mow around them and sends a message to the control system. The control system would then inform the owner, who would then have to clear the debris and tell the system to go back and mow the spots it missed.

Since the system is not able to care for itself, the owner would have several maintenance requirements that they would have to fulfill. The basic one would be to clean grass clippings out of the blade enclosure. How often this would need to be done would depend on a variety of factors, including how wet or dry the grass is, how much it grows between cuttings, and other similar things. Occasionally, the owner would have to clean off the sensor "eyes" of the robot. The system would be able to tell when this needed to be done, based on how hard it is for the "eyes" to get clear readings. Finally, the owner would have to get the blade sharpened periodically (once or twice a mowing season).

Visitors

When visitors come to the property, they would see a small green machine wandering purposefully across the lawn. Their initial reactions would be curiosity – "What is that?" or "How interesting!" If they ended up in the path of the robot, they might be concerned that it would run into them. Either they would move out of its way – causing the robot to stop and react to them, if it was close enough – or they would stand still, and the robot would steer around them. The obvious intelligence of the system's reactions would probably cause more curiosity on the visitor's part.

The Neighborhood

There are several initial reactions that adults in the neighborhood might have. On first seeing the robot moving around the lawn, with its green body and "bug eyes," a common thought might be "What the heck is that?" When the neighbors learned that it was an automatic lawnmower, there are several possible reactions. One is curiosity. They would want to learn more about it. Another possible reaction is fear. Concerned parents could wonder if it were safe to have a robot with a spinning blade running around the neighborhood. Would children and pets be safe? Technophobes and people who fear change, new ideas, and computers could also react badly to the robot.

Over the long term, these reactions would go one of three ways: neutral, positive, or negative. The neutral reaction is caused by acclimation to the idea. Neighbors would become used to the idea of the robot, and their initial reactions (curiosity or fear) would turn into acceptance – they would ignore the robot, because it had become a normal part of their world. The positive reaction would be continuing interest in the robot and the idea of an automatic lawnmower. The interested parties would possibly go on to purchase their own mowing systems. There are several reasons for a continuing negative reaction. One is that the neighbors are never convinced of the safety of the system. Another is being envious of the owner for having "cooler toys" – the "keeping up with the Joneses" scenario. The final one is technophobia; anyone who is afraid of technology and computers would never be really comfortable with the system.

Children

In considering the reactions of children to the ALS, we have to divide the group into two segments: younger children, whose life experiences are not very extensive, and older children, those who are somewhat more cognitive of how the world around them works.

Younger children will have one main response to the robot: curiosity. They see every new thing which enters their environment as something to investigate, a new toy to play with. They don't have a strong sense of self–preservation, and tend to go after things without thought as to whether it's safe or not. With its friendly appearance and the fact that it moves intelligently around the lawn, the ALS would be a very strong attractant for young children. Other reactions, such as fear, would only come about if they had a bad experience with the robot. The safety systems of the ALS are strongly targeted at this age group, and would prevent any harm from coming to curious children. Hopefully, after seeing that the robot stops and speaks warnings whenever they get close to it, the children would lose interest in the system and allow it to do its job.

Older children would have similar reactions as younger children, but there are some differences. First, older children have learned that some things in their environment can hurt them, and are somewhat more cautious in their dealings with strange machines. A second difference is that older children can also be deliberately mischievous or destructive if they want to be. The safety systems would keep them from getting hurt when they interact with the robot, and the security systems (see the Criminal section, below) would be a deterrent to vandalism. Vandalism is still a problem, however.

Animals

Animals will have two main reactions to the ALS. The first is curiosity. Many animals – including dogs, raccoons, and opossums – are very curious about new things in their environment. They tend to walk up to them, paw at them, and otherwise 'manhandle' them. If they took this approach with the robot, its first response would be to stop and emit warning sounds. This noise would most likely scare off any animals. If it didn't, the fact that the system was stopped and no longer moving would probably cause most animals to lose interest in the robot. If they physically manipulated the system, it would react with its security routines (see the section on vandalism, below). The second response is fear or caution. Rodents, cats, birds, and many other animals would be bothered by a moving motorized device wandering around the lawn, and would give it a wide berth. A third, but much less probable reaction would be inaction. Some small number of animals, such as turtles, might not respond at all, and would ignore the robot (or would respond with a total lack of motion). They would be avoided by the system, which would treat them as either mobile or immobile obstacles as the case warranted.

As a final note, experimentation with an actual prototype might show that some animals are bothered by the ultrasonic sensors, and would avoid the system completely.

Criminals

The criminal has two possible reasons to interact with the system: vandalism or theft. The motivations for vandalism are either the joy of breaking the law or the desire to hurt the owner and/or their property. The motivations for theft are profit or the desire to hurt the owner. The profit motivation depends on the perceived value of the robot. Does the thief think that they can get money for it? Is it easy to fence? How hard is it to steal (how good is its security)? I believe that the perceived value of the system would be low, assuming, of course, a reasonably intelligent thief. Without the control system and other accessories, the robot itself has no function, and its parts are not inherently very valuable on the open market. As a deterrent to the criminal, the robot can use its sensors and other systems as a built in security device. If someone picks up the robot and carries it away, the system would realize that the movement is caused by an external source, and react appropriately. It would track the direction that the robot is taken, and set off an alarm (both at the control system, and with the robot's speaker) if the robot was taken outside the boundaries of the yard. If the sensors detected that someone was hitting or otherwise violently treating the robot (due to sudden shocks, quick movements, stresses on the axles, etc.), it would also set off alarms. These would deter all but the most serious vandal or thief. All of these security protocols would be able to be deactivated by the owner.

Chapter 5
Evaluation and Conclusions

This chapter focuses on evaluating my thesis work. In the first part, I discuss my goals and how well I met them. In the following sections, I talk about aspects of my goals that I did not fully achieve, and then discuss what possible next steps there are in the task of opening up the field of consumer robotics.

Goals Met

I had two main goals for my thesis. The first was to promote the idea of consumer robotics. I wanted to show both the practicality and potential of this field. I believe that I have successfully illustrated the potentials. There are many household tasks that are suited to automation and robotics, and it will be possible, with dedicated research, development, and design efforts, to design solutions to these tasks that will be commercially viable and acceptable. I'm not as certain of the immediate practicality of these efforts. From all I have learned, I think that there is still some technological development required (especially in the case of the battery systems, which are not yet small and efficient enough) before all of the systems required to make these concepts work will be small, inexpensive, and effective enough for mass–market production. Given, however, that it will take industry some time to design, develop, and test these products, I still believe that it would be worthwhile to pursue their development.

My second goal was to design a robot lawncare system. I believe that the Automated Lawncare System is a successful achievement of this goal. The system is attractive, functional, and it fulfills all of the criteria I set for it. This is not to say that there aren't improvements and additions that could be made. Both during and after the exhibition of the ALS, I received a variety of comments and suggestions from gallery attendees and others who viewed my work. Among the things they pointed out were the fact that the blade guard needs some further thought (it works fine with grass, but would have difficulties with many of the weeds that occur in lawns), and that the "Automated Lawncare System" is not the most charismatic or consumer–oriented name I could have given the system. On the positive side, they found the concept to be intriguing, thought that I succeeded in giving the robot some sort of "personality," and a few wondered when they could get one of their own.

Goals Not Meet

There are still, however, some goals that still need work. I originally had planned to do full product development (including models) on the "home base" of the robot, and its control system. Due to several factors that slowed down design of the actual robot, and the thesis exhibition deadline, I was unable to pursue these system components to their final resolution. Without these finished components, I was unable to display the full system at the exhibit. Completing them would allow the ALS to be a stronger example of the consumer robotics concept I was trying to illustrate.

What's Next

Where do we go from here? There are several "next steps" that could be pursued at this point. In the case of the ALS, the next step is to move on to the prototype stage and do the actual product development. Put together a team of engineers and roboticists, build the system, and start testing the ideas that I have put forth in this thesis. Move the design into the real world.

Another "next step" is the conceptual development of "second generation" lawncare robots. Imagine more advanced technologies. Go forward five or ten years. What other functions can we fit into the design? Weeding, fertilization, and diagnosing plant diseases or the need to water are all possibilities for other functions.

A third future task is the continued promotion of consumer robotics. Effort needs to be given to this cause in order for it to flourish. One way to do this is with internet web pages. This document, as well as other information that I gathered in the course of my thesis, is contained in a web page that I am currently trying to find a permanent (or at least semi–permanent) home for. Other ways to promote consumer robotics include student design projects in the area, further thesis work (in other possible applications), and making relevant companies (such as Toro, John Deere, and Black and Decker) and robotics research groups aware of the research (and possibilities) in this field.

SOURCES CONSULTED

Print Sources

Castro, Elizabeth. *HTML for the World Wide Web*, 2nd ed. Berkeley, California: Peachpit Press, 1997.

Craig, John J. *Introduction to Robotics Mechanics and Control.* Reading, Massachusetts: Addison-Wesley, 1986.

Cushman, William H. and Daniel J. Rosenberg. *Human Factors in Product Design*, Advances in Human Factors/Ergonomincs, vol. 14. New York: Elsevier Science Publishing Company, Inc., 1991.

"Exmark - Professional Turf Care Equipment". [sales pamphlet] Beatrice, Nebraska: Exmark, 1997.

Iovine, John. *Robots, Androids, and Animatrons.* New York: McGraw-Hill, 1998.

Matthews, Peter. "The Rise of the Micro" in *Robots*, ed. Peter Marsh, 100-115. New York: Crescent Books, 1985.

McComb, Gordon. *The Robot Builder's Bonanza.* New York: TAB Books, 1987.

Moravec, Hans. "Machines with Mobility" in *Robots*, ed. Peter Marsh, 66-79. New York: Crescent Books, 1985.

Sanders, Mark S. and Ernest J. McCormick. *Human Factors in Engineering and Design.* New York: McGraw-Hill, 1987.

"Scag - The New Breed of Cost Cutters 1998". [sales pamphlet] Mayville, Wisconsin: Scag Power Equipment, 1998.

Sevart, John Bart and R. Lewis Hull. *Power Lawn Mowers: An Unreasonably Dangerous Product* . Durham, North Carolina: Institute for Product Safety, 1982.

Simons, Geoff. *Robots - The Quest for Living Machines.* London: Cassell, 1992.

"Toro Power Lawn Mowers". [sales pamphlet] Bloomington, Minnesota: The Toro Company, 1997.

Weinshenck, Susan, Pamela Jamar, and Sarah C. Yeo. *GUI Design Essentials.* New York: John Wiley & Sons, Inc., 1997.

Woodson, Wesley E., Barry Tillman, and Peggy Tillman. *Human Factors Design Handbook,* 2nd ed. New York: McGraw-Hill, 1992.

Electronic Sources

"Carefree Electrics". Bloomington, Minnesota: The Toro Company, 1997; available from http://www.toro.com/home/lawnmower/carefree.html; Internet; accessed 15 July 1998.

"Defining Terms". Stillwater, Oklahoma: Oklahoma State University, 1997; available at http://www.pp.okstate.edu/ehs/module3/mower/unit1.html; Internet; accessed 15 July 1998.

Gage, Douglas W. et al. "Other Communications Channels" in *Many Robot Systems*. (NRaD Robotics: 1997); available at http://www.spawar.navy.mil/robots/research/manyrobo/otherchans.html; Internet; accessed 15 July 1998.

"Ohio State University Extension Factsheet - Horticulture and Crop Science HYG-1190-93: Mowers and Mowing - Don't Bag It: The Lawn Maintenance Program". Columbus, Ohio: Ohio State University, 1993; available from http://www.ag.ohio-state.edu/~ohioline/hyg-fact/1000/1190.html; Internet; accessed 15 July 1998.

"Radio Direction Finding". BMG Engineering Inc, 1998; available at http://members.aol.com/BmgEngInc; Internet; accessed 15 July 1998.

"What is a Fuel Cell". Washington, DC: The Fuel Cell Commercialization Group, 1997; available from http://www.ttcorp.com/fccs/fc_what1.html thru /fc_what4.html; Internet; accessed 15 July 1998.